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DETERMINING THE EFFICIENCY OF INVESTMENTS AND EVOLVING TEMPORAL-SPATIAL TRENDS IN ENVIRONMENTAL GOVERNANCE USING THE STOCHASTIC FRONTIER ANALYSIS (SFA) MODEL

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Abstract

Environmental pollution has become a major global problem. However, despite increased environmental investment, studies have not clarified whether environmental pollution has been effectively controlled. On the basis of 1998-2014 panel data on three types of industrial waste from 31 mainland China provinces, a stochastic frontier analysis (SFA) model was used to estimate the input efficiency of environmental governance in China, explore the overall characteristics of input efficiency, and explore the evolving trends in terms of the degree of match between environmental input efficiency and input efficiency in various provinces. The results indicate that (1) the input and output of the environmental governance of industrial pollution are positively correlated. The population, industrialization level, and area of a region have a negative impact on the efficiency of investment in environmental governance, whereas gross domestic product, education level, urbanization, and foreign direct investment have a positive impact on it. (2) Generally, the trend in the input efficiency of China's environmental governance is downward. The average value of the central provinces is the only one that is greater than the national average, and the efficiency of environmental governance in each province exhibits a downward trend. Convergence analysis indicates that the efficiency of environmental investment in various Chinese provinces is moving toward differentiation and that the provinces within each region have developed to a balanced level, although a large gap exists between their equilibrium levels. (3) The degree of matching between investment efficiency is not very high, and only six provinces in central and east China exhibit the characteristics of "high input-high efficiency." On the basis of these conclusions, we propose four key policy recommendations.

Key words: environmental governance efficiency, temporal-spatial evolution trend, Mainland China; three types of industrial waste, scholastic frontier analysis

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1. Introduction

In tandem with the steady development of the global economy in the 21st century, the ecological environment has been severely damaged, and environmental pollution has become a global problem. According to data released by the World Bank, global gross domestic product (GDP) reached US$74 trillion in December 2016. The United States, ranked the number one producer, accounted for 24.32% of the total, whereas China, ranked second, accounted for 14.84% of the total, making it the world's second-largest economy. However, this rapid economic success has been achieved at the expense of massive energy consumption and resultant carbon emissions. Recently, environmental pollution in mainland China has become an increasingly severe problem. Frequent haze problems and water pollution incidents have

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attracted global attention, although the most prominent problem is air pollution. For instance, the *Environmental Performance Index: 2016 Report* released by Yale University determined that air quality in China is ranked second from last among 180 countries and regions, superior only to that of Bangladesh. A report entitled *The Cost of Air Pollution: Strengthening the Economic Case for Action* released by the World Bank and Institute for Health Metrics and Evaluation by the University of Washington in September 2016 stated that “China loses 10 percent of its GDP because of environmental pollution, resulting in premature death, loss of working hours and related welfare spending.”

Industrial practices in most developing countries and in emerging industrialized countries indicate that environmental degradation and resource depletion are substantial problems during economic development. Economic growth and industrial development consume vast quantities of natural resources. Consequently, China’s environmental pollution problems are mainly caused by industrial emissions and waste. Since 2002, China has entered the mid-latter stage of accelerated industrial development. Their basic approach is to promote the rapid growth of the national economy by developing industry, and heavy industry is growing faster than light industries. According to *China Environment News*, managed by the Ministry of Environmental Protection of China, industrial pollution accounts for more than 70% of total pollution in China and three types of industrial waste have become major sources of pollution. In recent years, the Chinese government has begun to understand the severity of environmental pollution and has increasingly emphasized environmental governance. It has therefore enhanced investment in the environment to curb carbon emissions and reduce pollution. However, despite more investment in the environment, studies have not clarified whether environmental pollution has decreased; thorough analysis and discussion of this concern is therefore required (Joldes et al., 2017; Mirandola and Lorenzini, 2016; Nemes et al., 2015; Outapa et al., 2017; Xing, 2017; Zheng et al., 2018).

Previous studies on the efficiency of environmental input have mainly focused on industries, enterprises, products, and international trade (Abed-Elmdoust and Kerachian, 2016; Callens and Tyteca, 1999; Pearson, 1987; Ruth, 2000). However, studies on Chinese regions and comparisons between are scant, and China is a country with a vast territory containing more than 30 provincial governments. We must therefore measure environmental efficiency at a provincial level. Recently, measurement and calculations of environmental input efficiency conducted by Chinese researchers have focused on certain provinces and single pollutants. For example, through data envelopment analysis (DEA) and stochastic frontier analysis (SFA), Some scholars have studied the investment efficiency of the industrial environment in Liaoning province and the factors that influence it. They determined that efficiency values differed in space and time within the region (Bianco et al., 2017; Gai et al., 2014; Tong et al., 2012). Previous studies mostly focused on the governance performance in a certain region or with regard to a certain pollutant, while there are few researches on the overall characteristics of the provinces in mainland China. Besides, the majority of studies are static ones which cannot reflect the overall dynamic changes of pollution control performance. Nor can they reveal the different characteristics of different provinces. It is worth noting that China is a country with many provinces. Since there are large gaps between these provinces in terms of natural geography, population resources, economic development and social development, the environmental governance problems they face and their governance performance will be significantly different as well. However, for the governance of different provinces and various pollutants, questions arise as to the level of efficiency and the temporal–spatial characteristics that are evolving. These problems have not been clearly addressed in existing studies. Therefore, this study focused on 31 provinces in mainland China and three forms of industrial waste to analyze the efficiency of environmental governance on the basis of the following research questions: 1. What is the overall situation regarding environmental governance input efficiency in various provinces of China? 2. What are the current trends in terms of changes and the spatial distribution regarding the input efficiency of environmental governance in Chinese provinces? 3. What is the input intensity of environmental governance in each province and to what extent do input and efficiency match? Firstly, the environmental governance performance of all provinces in China and the mean of each province from 1998 to 2014 were measured. Secondly, the temporal and spatial variation trends of environmental governance investment efficiency were analyzed to compare and analyze the similarities and differences between these regions and comprehensively understand the current situation, which can provide some guiding suggestions for the industrial pollution control work at the macro level and the regional environmental governance work at the meso level. Finally, by analyzing the matching of environmental investment and efficiency in each province, it can also encourage each region to optimize their investment strategies in future environmental governance work and effectively improve the governance efficiency.

2. Literature review

Previous studies have proposed two methods for measuring environmental input efficiency: input efficiency itself is not included in the calculations but is expressed by the ratio of added value to pollution emission (Fan et al., 2016). For example, Schaltegger and Sturm (1990) first proposed ecological efficiency, which they defined as the ratio of economic added value to environmental impact; Müller and Sturm

(2001) proposed a calculation formula for calculating ecological efficiency and they determined that ecological efficiency was equivalent to environmental performance or economic performance. These concepts referred to the environmental impact and economic value resulting from economic activities within a certain period. Kortelainen (2008) defined environmental efficiency as the ratio of added value to the environmental damage loss that occurs as a result. The second type of environmental efficiency can also be termed environmental comprehensive efficiency or environmental total factor efficiency. Reinhard et al., (1999) extended the concept of environment efficiency to include the ratio of the possible minimal harmful input and current harmful input when ordinary output (e.g., capital and labor) and output remain unchanged under the established level of technical practice. This measure reflects the ratio of input and output and has been widely recognized and applied by researchers (Wang et al., 2010).

In the current stage, environmental investment efficiency is mainly studied from the micro, meso and macro perspectives. At the micro level, the environmental governance efficiency is mainly measured as to an industry, an enterprise or a product. For example, some scholars have used data envelopment analysis (DEA) to measure the efficiency of environmental management in Norwegian industrial enterprises (Larsson and Telle, 2008). Chen et al. (2010) applied DEA to analyze the pollution control efficiency of waste incinerators in Taiwan. Reinhard et al., (2000) calculated the environmental efficiency of Dutch dairy farms using the DEA and SFA methods respective, compared the results obtained by the two methods, and found that SFA is a more suitable method. At the meso level, previous studies mainly measured and compared the environmental governance efficiency of a specific region, a city or multiple provinces. For instance, Zheng (2011) used the DEA-CCR model to evaluate the comprehensive efficiency, technical efficiency and scale efficiency of industrial pollution control efficiency with 8 regions in Hangzhou, China as the decision-making units. Guo and Zheng (2009) used DEA to measure the efficiency of input and output of environmental governance in Henan Province, the results of which show that under the vertical comparison, the environmental governance efficiency of the same region differs greatly at different time nodes. Furthermore, the reasons for differences in environmental investment efficiency in different years and the room for improvement were discussed. By conducting estimation using SFA, Tan et al., (2015) found that there are significant regional differences in China in terms of environmental efficiency, with the environmental efficiency in the eastern region generally higher than that in the western region. At the macro level, most scholars have carried out quantitative analysis based from a national perspective, and some scholars have even conducted cross-country researches. Filippini and Hunt, (2011) believe that improving energy efficiency is a key measure as environmental issues are prominent nowadays, who used SFA to measure the energy use efficiency of 29 OECD countries. Based on the DEA-CCR model, Dong (2008) and other scholars conducted international comparison and historical comparison of environmental governance efficiency in 30 countries. From the perspective of international comparison, China's investment in environmental protection is below the average of the 30 countries. From the perspective of historical comparison, China increased capital and manpower input year by year, but its environmental governance efficiency was improved substantially, and the scale benefits remain unchanged.

Through systemizing and analyzing previous literatures, it is found that DEA and SFA are methods commonly used to measure the environmental efficiency at the regional level. The principle underlying SFA is to divide the actual output into production function, random factors, and technical inefficiency to determine the frontier boundary with the maximum likelihood of estimation. Its frontier surface is random; thus, the conclusion is close to the actual situation. By contrast, DEA divides actual output into the production frontier and technical inefficiency. The production frontier comprises technologically effective samples, and its shape is determined by the information within these samples. Abnormal points or white noise influence the effectiveness and sensitivity of the results. Moreover, this method can often lead to no solution or unbounded solution in the large sample calculation process (Lei and Huang, 2015; Song et al., 2012; Wang et al., 2013). Compared with DEA, the biggest advantage of SFA is that it considers the influence of random factors on output and is more suitable for large sample calculation. Therefore, this study chose SFA for measuring and calculating environmental efficiency.

At the regional level, most researches focused on certain region or a certain city, and there has not been a comprehensive study exploring all provinces in mainland China. Besides, most of them are based on static perspectives, and there are extremely rare researches with dynamic and comparative analyses. In the process of selecting variables, only input and output variables were considered, whereas other exogenous variables failed to be included in the analysis process. All this have caused certain limitations of currently available researches. Because China is a unitary country with a vast territory, its central government has jurisdiction over more than 30 provincial governments, and it has adopted a system of central and local fiscal decentralization. Hence, financial investment in environmental governance varies by province. The efficiency of environmental input depends not only on changes in input and output but also on numerous economic and social factors (Zhao and Song, 2013). Therefore, when measuring the efficiency value, the author incorporates exogenous variables reflecting economic and social environments into the analysis process. This facilitates in-depth exploration of its temporal–spatial evolution characteristics. Depending on how the current situation is clarified, countermeasures to support future development are proposed.

3. Research design

3.1. Model construction

Based on the Battese and Coelli model, this study estimated the efficiency of environmental investment and applied two-stage analysis to consider the impact of environmental factors on technical efficiency. It can be expressed as (Eq. 1) and (Eq. 2):

$$Ln(Y_{it}) = \beta X_{it} + V_{it} - U_{it} \quad (1)$$

$$m_{it} = \delta Z_{it} + W_{it} + \omega_{it} \quad (2)$$

where *i* and *t* represent region and year, respectively. In Eq. (1), Y_{it} and X_{it} denote the output variable and input variable, and V_{it} is the random variable representing the statistical error; U_{it} is a nonnegative random variable that represents the inefficiency item and is normally distributed $N(m_{it}, \sigma 2\ u)$. In Eq. (2), Z_{it} denotes the environment variable; ω_{it} is the stochastic error term; W_{it} is the constant term representing management inefficiency, and the final efficiency is thus calculated as (Eq. 3):

$$Eff_{it} = Exp(-W_{it}) \quad (3)$$

3.2. Variable selection

Studies have shown that industrial sewage pollution accounts for a large proportion of the total environmental pollution resulting from China's modernization (Lu and Feng, 2014). The main pollutants produced by industry are three types of industrial waste: waste water, waste gas, and solid waste. Therefore, this study focused on investment in three industrial waste control projects, the operating costs of governance facilities, and the quantity of construction projects to determine the input of environmental governance. The indicators include annually completed investment in industrial waste water treatment projects, industrial waste gas treatment projects, and industrial solid waste treatment projects; total annual construction projects for industrial waste water treatment, industrial waste gas treatment, and industrial solid waste treatment; operating expenses for industrial waste water treatment facilities and industrial waste gas treatment facilities; the number of industrial waste water treatment facilities and industrial waste gas treatment facilities.

Output indicators primarily include the amount of removal of chemical oxygen demand (COD), oil, volatile phenol, sulfur dioxide, smoke, and dust as well as the comprehensive use of solid waste (Dominguez et al., 2016; Fan et al., 2016; Lei and Huang, 2015; Zheng., 2011; Tan et al., 2016). Previous studies have determined that the investment efficiency of environmental governance is affected by social, economic, and geographic factors, such as population, economic development, urbanization, industrialization and educational development, foreign investment, and area of a province (Song et al., 2013). Therefore, seven environmental variables were included in this study, namely population, GDP, urbanization, industrialization, average years of education, FDI, and field. To ensure the uniformity and integrity of the variables and minimize the number of missing values, the author selected 31 provinces, excluding Hong Kong, Macao, and Taiwan.

3.3. Data

The data were taken from the various editions of the *China Environment Yearbook*, *China Statistical Yearbook*, and *China Demographic and Employment Yearbook* published from 1998 to 2014. To eliminate the influence of inflation factors on economic variables, the consumer price index (CPI) is used to handle economic variables, and the statistical results are presented in Table 1. Of the three industrial types of waste, the average annually completed investment in industrial waste gas treatment was the largest at 740.7938 million yuan, followed by the average annually completed investment in industrial waste water treatment, which stood at 394.6213 million yuan, and the average annually completed investment in industrial solid waste treatment which totaled just 58.5371 million yuan. The average operating costs for industrial waste gas treatment facilities are higher than those for industrial waste water treatment facilities, indicating that China prioritizes waste gas over waste water and solid waste.

Of construction projects, the mean value of annual treatment projects for waste gas, waste water, and solid waste was 164.22, 158.63, and 18.19, respectively. The mean value of treatment facility projects for waste gas is much higher than that for waste water, indicating that China's current environmental governance projects are dominated by waste gas governance and that the amount of equipment used for industrial waste gas treatment greatly exceeds that used for waste water and solid waste. The standard deviation of the operating expenses for waste gas treatment facilities is the largest at 297,939.50 yuan. This indicates large regional differences in the operating costs of waste gas treatment facilities.

In terms of the output variables, the mean value of volatile phenol removal is the smallest (2242.69 tons). The mean value of comprehensive utilization for solid waste is the largest (34.9332 million tons). Overall, of the three types of industrial waste, solid waste governance receives the least investment, whereas the comprehensive utilization of solid waste receives the most investment, probably because solid waste has the highest rate of recoverability. However, waste gas and waste water are not only difficult to control and treat, their treatment is also irreversible because once the environment is contaminated, its recovery is difficult. Among the environmental variables, the average provincial GDP is 808.539 billion yuan, whereas the average provincial population is 419.29 million. The standard deviations for these variables are much higher than for the environmental variables, indicating large interprovincial differences in economic development and population distribution. The value for mean years of schooling is 8.05 years with a minimum standard deviation because China's 9-year compulsory education policy in China. A small gap exists between the means of urbanization and industrialization, both of which are approximately 45%. The minimum value of urbanization is 44.42%, slightly lower than that of industrialization (45.47%), although the maximum value for urbanization is far higher than that of industrialization, and its standard deviation is also substantially higher, suggesting that interprovincial urbanization differences are significantly higher than interprovincial industrialization difference. For instance, the urbanization rate is low in underdeveloped areas of western China but high in eastern coastal areas

Table 1. Descriptive statistics for input variables

Variable		***Unit***	***Obs***	***Mean***	***Std. Dev.***	***Min***	***Max***
Output variable	Amount of solid waste comprehensive utilization	ten thousand tons	527	3493.32	3770.13	0.00	20235.00
	Amount of sulfur dioxide removal	ton	527	653990.00	776431.70	0.00	5388260.00
	Amount of smoke and dust removal	ten thousand tons	527	1290.00	1450.00	0.01	13100.00
	Amount of chemical oxygen demand (COD) removal	ton	527	439777.70	669650.40	0.00	8653697.00
	Amount of oil removal	ton	527	12004.24	18650.22	0.00	162777.00
	Amount of volatile penol removal	ton	527	2242.69	4354.25	0.00	65213.00
Input variable	Annually completed investment of industrial waste gas treatment projects	ten thousand yuan	527	39462.13	43914.36	0.00	295540.00
	Operating expenses of industrial waste water treatment facilities	ten thousand yuan	527	120954.30	141215.00	48.00	966723.00
	Annually completed investment of industrial waste gas treatment projects	ten thousand yuan	527	74079.38	113765.40	0.00	1281351.00
	Operating expenses of industrial waste gas treatment facilities	ten thousand yuan	527	208410.50	297939.50	0.00	2243764.00
	Annually completed investment of industrial solid waste treatment projects	ten thousand yuan	527	5853.71	10092.89	0.00	83148.00
	Total annual construction projects of industrial waste water treatment	pcs	527	158.63	203.98	0.00	1789.00
	Set number of industrial waste water treatment facilities	set	527	2344.63	2062.54	9.00	10608.00
	Total annual construction projects of industrial waste gas treatment	pcs	527	164.22	158.13	0.00	1188.00
	Set number of industrial waste gas treatment facilities	set	527	5348.68	4132.37	13.00	22311.00
	Total number of construction projects of industrial solid waste treatment	pcs	527	18.19	19.36	0.00	130.00
Environ-mental variable	Population	ten thousand	527	4192.90	2660.36	252.00	10724.00
	GDP	100 million yuan	527	8085.39	8572.85	91.18	48555.34
	Education	year	527	8.05	1.28	2.95	12.03
	Urbanization	%	527	44.42	16.26	13.38	89.60
	Industrialization	%	527	45.47	8.69	16.90	66.80
	FDI	%	527	7.32	13.05	0.00	129.14
	Field	10k km^2	527	30.98	38.12	0.63	166.50

4. Empirical results and analysis

4.1. Estimation of environmental governance efficiency

Because numerous input variables are used, factor analysis was applied to integrate the variables to avoid multicollinearity influencing the regression. When 10 input variables were extracted, the Kaiser–Meyer–Olkin (KMO) value was 0.8008. Factors whose eigenvalues are higher than 1 were selected, two of which had contribution rates of 0.7013 and 0.2513, respectively. The cumulative contribution rate was 0.9527. To illustrate the variance in investment in each province, a comprehensive factor scoring method was used to estimate the investment in each province. Table 2 presents the results of SFA parameter estimation, where $\gamma = 0.9440$ and the likelihood ratio statistical test is significant at a 1% level. With γ approaching 1, the deviation of actual output from the frontier output is mainly the result of the technological inefficiency of production, and a SFA model is therefore appropriate. Additionally, the error term in Eq. (3) has an obvious composite structure. Using an SFA model rather than ordinary least squares for the panel data obtained from the 31 Chinese provinces is therefore reasonable. Beta0, Input1, and Input2 all passed the significance test, and the coefficients are all greater than 0, indicating that the input and output of the environmental governance of industrial pollution are positively correlated.

Among the environmental variables, seven passed the significance test. Of these, the coefficients of population, industrialization, and field are positive, indicating that they are negatively correlated with environmental efficiency. Population generally exerts greater pressure on the environment, hence its negative influence on the efficiency of environmental governance. When industrialization is higher, the amount of energy that is consumed increases, discharging more industrial waste; thus, the degree of industrialization has a negative impact on the efficiency of environmental governance. Larger fields involve more onerous environmental governance, which has a negative impact on the efficiency of environmental governance. The coefficients of GDP, Education, Urbanization, and FDI are all smaller than 0, indicating that these four variables are positively correlated with environmental efficiency. In economically developed areas, technology and education are relatively strong, and pollution control technologies advance rapidly; thus, GDP and Education are positively correlated with environmental performance. Both economic development and educational enhancement within a province therefore enhance the efficiency of environmental governance. Furthermore, the results indicate that FDI promotes improvements in environmental quality during the reform process and in the context of China's increasing urbanization.

4.2. Overall spatial and temporal distribution of the input efficiency of environmental governance

From the estimated annual efficiency of 31 provinces, the mean total from 1998 to 2014 can be obtained. Fig. 1 shows the temporal changes in the overall mean value of the input efficiency of China's environmental governance. It indicates that input efficiency declined from 0.76 in 1998 to 0.39 in 2014. Conversely, total investment in industrial pollution control in China increased markedly from 12.20461 billion yuan in 1998 to 99.7651087 billion yuan in 2014. Thus, for a long time, environmental governance has paid "more attention to input and less to output" and prioritized increasing investment in environmental governance without considering the practical consequences.

Table 2. SFA parameter estimation results

Parameter	***Coefficient***	***SD***	***T value***
Cost function			
Beta0	2.7510	0.0674	40.8084***
Input1	0.2524	0.0409	6.1678***
Input2	0.2940	0.0357	8.2360***
Inefficiency function			
Population	12.8618	1.3526	9.5090***
GDP	-0.0016	0.0003	-4.5581***
Education	-0.0004	0.0001	-5.1570***
Urbanization	-1.6349	0.2350	-6.9557***
Industrialization	0.1415	0.0264	5.3591***
FDI	-0.2225	0.0367	-6.0549***
Field	0.0463	0.0106	4.3537***
Variance parameter			
sigma-squared	5.5001	0.9438	5.8280***
gamma	0.9440	0.0122	77.6634***
LR test value	708.41956***		

*Note: ***p<0.01, **p<0.05, *p<0.1*

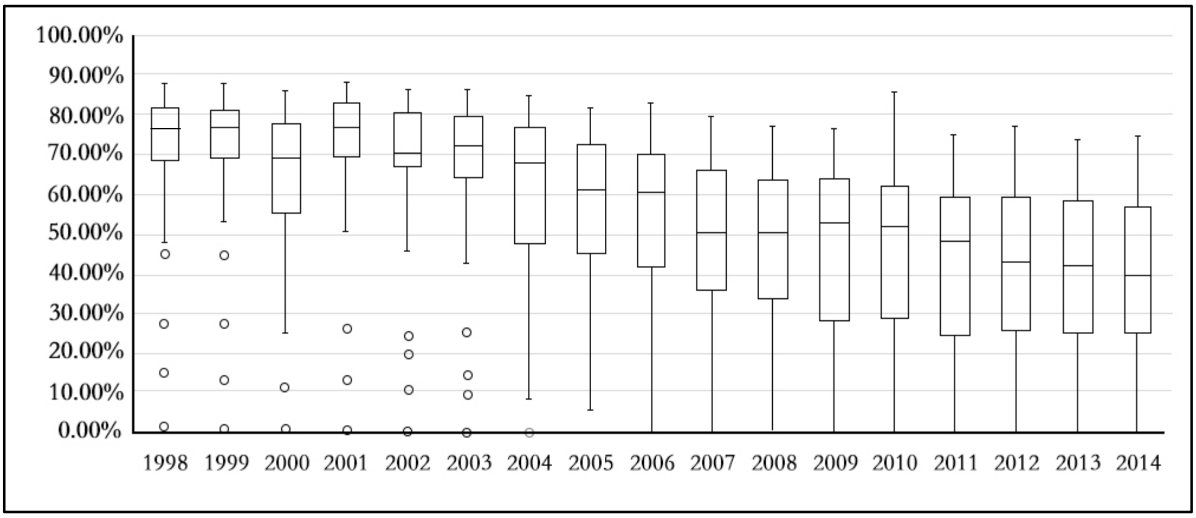


Fig. 1. Temporary change trend of the input efficiency of environmental governance (1998-2014)

From 2001 to 2005, 2006 to 2010, and 2011 to 2015, China's Tenth Five-Year Plan, Eleventh Five-Year Plan, and Twelfth Five-Year Plan, respectively, were implemented. At the Copenhagen United Nations Climate Change Conference (2009) and the Paris Conference (2015), China committed to "cut the CO_2 emissions per unit of GDP by 40%–50% by year 2020 from the year 2005 level" and "carbon dioxide emissions per unit of GDP will fall by 60–65% by 2030 from 2005 level." From 2010 to 2015, China's environmental protection polices received unprecedented attention, and total investment in environmental governance as a share of GDP has increased, whereas environmental efficiency has declined. Environmental assessment has also lagged, lacking both special supervision and a feedback mechanism, which makes environmental input having an effect difficult.

Table 3 presents the maximum, minimum, mean, and standard deviations of input efficiency of environmental governance in the provinces of the eastern, central, and western regions from 1998 to 2014.

The maximum value (88.08%) is in Hebei Province, whereas the minimum (0.24%) is in Tibet. The average efficiency of eastern provinces ranges between 6.80% and 78.98%, a large span indicating an unsatisfactory balance. The overall mean is only 53.62%. The peak efficiency is in Hebei, Liaoning, and Jiangsu provinces, and the lowest efficiency is in Hainan Province, Beijing, and Tianjin. The average efficiency of the central provinces ranges between 57.29% and 78.27%, and the overall mean is 67.34%, higher than in both the central and western regions. Anhui Province has the largest mean and Jilin Province the smallest. Generally, the efficiency values of central-region provinces do not differ greatly; the standard deviation is only 13.95% and the overall efficiency value is relatively high. The average efficiency of provinces in the west ranges between 0.16% and 64.52%. The largest mean is in Yunnan Province and the smallest is in Tibet. The mean differences between the provinces in the region are relatively large but none are especially high because the overall mean of the region is 43.15%, far smaller than that of the eastern and central regions. At a national level, the average efficiency of the 31 provinces is 54.22%. Only the mean of the central provinces exceeds the national mean, and the means of the eastern and western regions are both lower than the national average.

Provinces in the eastern region vary greatly; the efficiency values of Beijing and Tianjin in northern China are far lower than those of Zhejiang and Jiangsu provinces in the southeast, reflecting the occurrence of the "Matthew effect." The efficiency values of western China provinces are relatively low, and the regional efficiency values are also lower than those in the eastern and central regions.

The central-region provinces exhibit fewer differences and have achieved relatively balanced development, mainly because the pollution industry is moving from the east to the west. This is because environmental protection policy in China's coastal areas became stricter during the Eleventh Five-Year Plan period. In terms of environmentally sensitive areas, the west's ecological environment is fragile; thus, any slight disturbance may have a dramatic and irreversible impact, such as local desertification or water source pollution. Combined with a weak economic foundation, the unsatisfactory governance capability of local government, and fewer technological advantages, and less talent, greater environmental risks exist. Hence, the investment efficiency of environmental governance has therefore remained low.

4.3. Evolving trends and convergence analysis of the input efficiency of environmental governance in various provinces

The province codes in Fig. 2 are consistent with those in Table 3, where 1 denotes Beijing, and 31 denotes Xinjiang.

Table 3. Input efficiency of eastern, central, and western provinces

Area	*Code*	*Obs*	*Mean*	*Std.Dev.*	*Min*	*Max*
Beijing (BJ)	1	17	28.13%	3.63%	23.66%	35.53%
Tianjin (TJ)	2	17	35.32%	12.74%	19.90%	52.36%
Hebei (HE)	3	17	78.98%	8.10%	62.92%	88.08%
Liaoning (LN)	6	17	77.60%	2.98%	73.82%	82.71%
Shanghai (SH)	9	17	54.20%	9.43%	38.91%	68.32%
Jiangsu (JS)	10	17	75.80%	5.73%	66.96%	85.52%
Zhejiang (ZJ)	11	17	56.79%	13.75%	33.88%	78.02%
Fujian (FJ)	13	17	46.71%	15.86%	16.29%	68.53%
Shandong (SD)	15	17	72.75%	9.28%	55.75%	86.44%
Guangdong (GD)	19	17	52.10%	14.68%	35.43%	77.70%
Guangxi (GX)	20	17	58.19%	12.48%	40.23%	77.28%
Hainan (HI)	21	17	6.80%	4.39%	1.22%	14.94%
Total result of East provinces	**East**	**204**	**53.62%**	**23.42%**	**1.22%**	**88.08%**
Shanxi (SX)	4	17	71.16%	11.03%	56.62%	86.56%
Inner Mongoria(NM)	5	17	59.61%	23.28%	24.63%	84.55%
Jilin (JL)	7	17	57.29%	8.63%	44.23%	70.92%
Heilongjiang (HLJ)	8	17	68.91%	7.73%	55.73%	80.13%
Anhui (AH)	12	17	78.27%	5.47%	67.94%	85.43%
Jiangxi (JX)	14	17	65.27%	15.07%	35.48%	81.56%
Henan (HA)	16	17	77.61%	7.83%	63.44%	87.52%
Hubei (HB)	17	17	66.25%	10.63%	46.55%	83.22%
Hunan (HN)	18	17	61.66%	12.33%	43.10%	79.82%
Total result of Middle provinces	**Middle**	**153**	**67.34%**	**13.95%**	**24.63%**	**87.52%**
Chongqing (CQ)	22	17	50.69%	16.89%	24.49%	74.10%
Sichuan (SC)	23	17	62.70%	11.93%	46.56%	82.81%
Guizhou (GZ)	24	17	49.60%	25.02%	18.45%	80.39%
Yunnan (YN)	25	17	64.52%	15.09%	37.09%	82.98%
Tibet (XZ)	26	17	0.16%	0.24%	0.00%	0.67%
Shaanxi (SN)	27	17	49.15%	23.69%	11.44%	78.93%
Gansu (GS)	28	17	55.89%	13.38%	39.35%	75.90%
Qinghai (QH)	29	17	23.05%	27.11%	2.37%	70.72%
Ningxia (NX)	30	17	33.89%	24.82%	7.64%	74.87%
Xinjiang (XJ)	31	17	41.86%	18.09%	24.35%	72.57%
Total result of West provinces	**West**	**170**	**43.15%**	**26.45%**	**0.00%**	**82.98%**
Total result of Nation		**527**	**54.22%**	**24.13%**	**0.00%**	**88.08%**

Note: In 1986, the Chinese government divided the 31 provinces into eastern, central, and western regions on the basis of the Seventh Five-Year Plan. By convention, this paper follows this standard.

To identify notable trends in the investment efficiency of environmental governance in the provinces, temporal changes in efficiency value in the 31 provinces were explored. Fig. 2 comprises a dynamic trend chart illustrating the investment efficiency of environmental governance in each province from 1998 to 2014. Of the provinces, those with codes 3, 4, 6, 10, 12, 15, and 16 have high efficiency values with no obvious downward trend and low volatility. These provinces are concentrated in the central area. The eight provinces with codes 5, 11, 22, 23, 24, 25, 29, and 30 have significant downward trends with large declines; these provinces are mainly in the western area. The peak values in the investment efficiency of environmental governance in most provinces appear in approximately 2000, specifically those with codes 3, 4, 5, 6, 7, 14, 16, 25, 29, 30, and 31. The turning point in the decline in efficiency occurs from 2001 to 2002, when the Tenth Five-Year Plan began. Thus, although 31 provinces exhibit a declining volatility trend, the evolution of investment in each province indicates a slightly different trend.

To analyze the interprovincial differences, convergence analysis was conducted with convergence judged using the criteria developed by previous scholars (Miller and Upadhyay, 2002). It can be expressed as (Eq. 4):

$$(1/T)Ln(Eff_{it} / Eff_{io} = a + bEff_{io} + u \quad (4)$$

where, $b = 1/T(e^{-ConT} - 1)$, T is time span; *Con* denotes the rate of convergence; if *Con* is negative, the data converges; in other words, the direction of development is the same; thus, if it is positive, the data diverges, and the direction of development is different. To reduce the impact of the cycle factor, the means of 1998 and 2014 are used as the initial and final items of data in the calculation. The results are presented in Table 4. The coefficient is greater than 0, indicating that absolute convergence does not exist, the value diverges, and the environmental investment efficiency of Chinese provinces tends to differentiation. Conditional convergence analysis was performed following absolute convergence analysis. It can be expressed as (Eq. 5):

$$dLn(Eff_{it}) = Ln(Eff_{i,t-1}) = a + bEff_{i,t-1} + u \quad (5)$$

where $b=e^{-Con \cdot Len}-1$, $Eff_{i,t}$ is the environmental investment efficiency of i in the t phase; *Len* is the determined length of each where, for this paper, a length of 2 years was selected. A two-way fixed effect model was used to eliminate the influence of time changes on the model. As shown in Table 5, the coefficient is less than 0, which indicates conditional convergence, and the areas develop toward the equilibrium level although a large gap exists between the equilibrium levels.

4.4. Matching analysis of input efficiency and input intensity rankings for environmental governance

Rank-eff represents the ranking of Input Efficiency and rank-inv represents the ranking of input intensity. The results in Fig. 3 were obtained once the input efficiency of environmental governance and the corresponding input intensity were ranked. A small gap between two values indicates a close match, and vice versa.

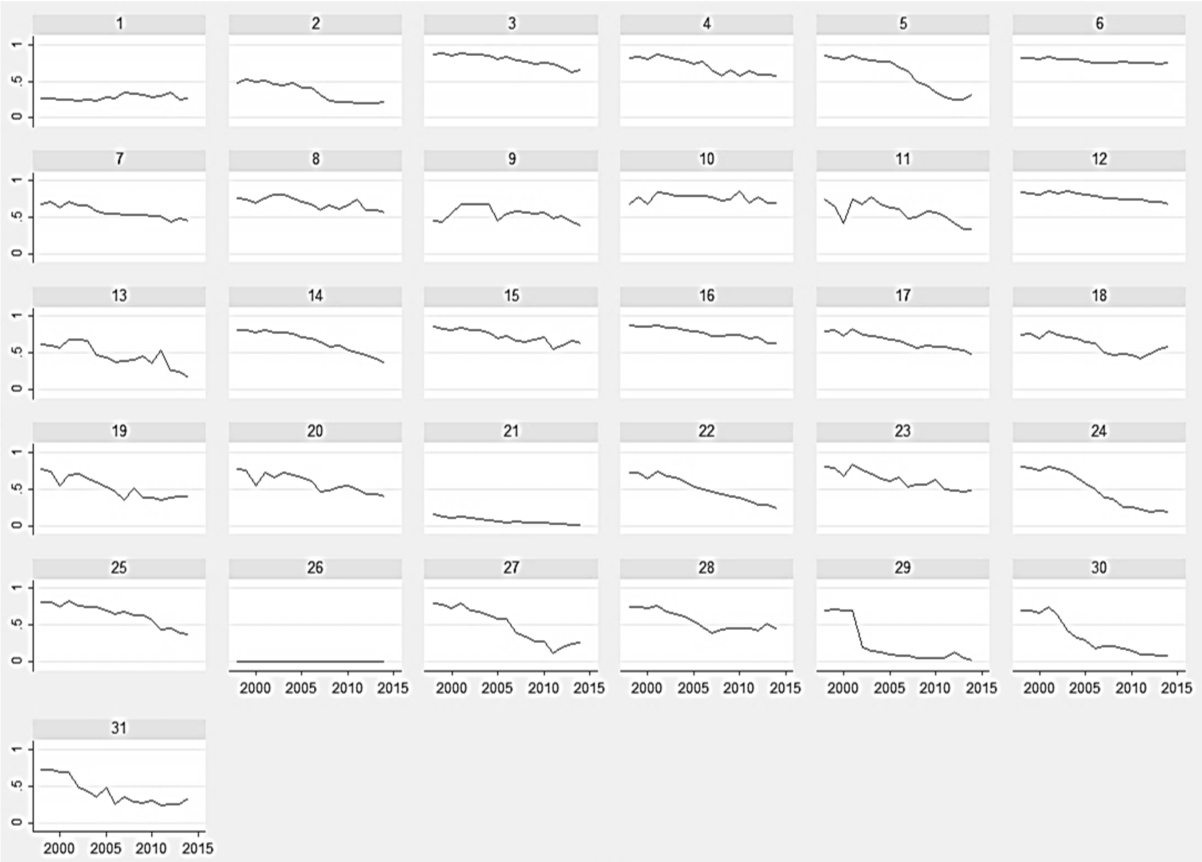


Fig. 2. Evolving trends in the investment efficiency of environmental governance in Chinese provinces

Table 4. Estimated Results for Absolute β Convergence

	Overall	***East***	***Middle***	***West***
Coefficient	0.0592	0.0477	-0.0421	0.0563
t	6.35	2.23	-0.53	4.56
Sig.	0.0000	0.0500	0.6110	0.0020
R^2	0.5815	0.3313	0.0389	0.7222
Convergence	No	No	No	No

Note: The division of the central, eastern, and western areas in Table 4 is the same as that in Fig. 3

Table 5. Estimated results for relative β convergence

	Overall	***East***	***Middle***	***West***
Coefficient	-0.3754	-0.1296	-0.0980	-0.4221
t	-10.74	-2.8	-2.06	-6.3
Sig.	0.0000	0.0060	0.0420	0.0000
R2	0.2371	0.2225	0.2954	0.3082
Convergence	Yes/0.4706	Yes/0.1388	Yes/0.1031	Yes/0.5484

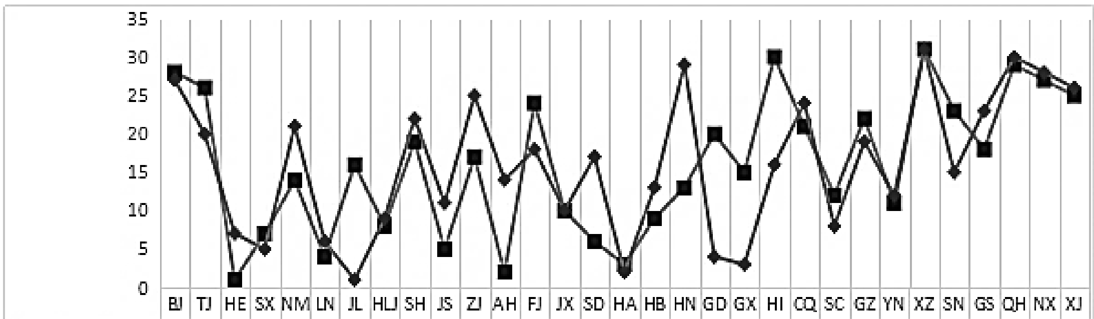
Note: The division of the central, eastern, and western areas in Table 5 is the same as that in Fig. 3

However, the rankings of investment and efficiency do not exactly match the results in Fig. 3. To subdivide the provincial conditions, the top 10 provinces in terms of input or efficiency are classified as high input and high efficiency provinces, provinces with medium input or efficiency as classified as medium input and medium efficiency provinces, and the other 11 provinces are classified as low input and low efficiency provinces. Subsequently, using the data in Fig. 4, a distribution diagram of the provincial input intensity and input efficiency of environmental governance is created.

As Fig. 4 shows, 14 provinces are high input intensity–high efficiency, medium input intensity–medium efficiency, and low input intensity–low efficiency; that is, their degree of input intensity matches their degree of efficiency. However, most provinces do not exhibit matches in the degrees of input intensity and efficiency, but no provinces have high input intensity–low efficiency or low input intensity–high efficiency status. Specifically, Hebei, Henan, Heilongjiang, Liaoning, Shanxi and Jiangxi provinces have high input intensity–high efficiency where investment in environmental governance for these provinces is a virtuous circle. The investment of environmental governance in Tibet, Qinghai, Beijing, Tianjin, Chongqing, Ningxia, and Xinjiang is low input intensity–low efficiency, suggesting substantial room for improvement exists. Jiangsu, Anhui, Hubei, and Shandong provinces are medium input intensity–high efficiency. whereas Shanghai, Zhejiang, Gansu, Inner Mongolia, and Hunan are low input intensity–medium efficiency, indicating that investment has been affected in these areas, and all have improved prospects for development. Overall, a large gap exists between rankings of the efficiency of environmental input and input intensity, and the degree of matches is therefore low.

5. Conclusions

In this study, we investigated three types of industrial waste in 31 provinces of mainland China. SFA was used to calculate the investment efficiency of environmental governance in mainland China and to explore the impact of exogenous variables, including population, education, urbanization, and industrialization, on environmental efficiency.



	BJ	TJ	HE	SX	NM	LN	JL	HLJ	SH	JS	ZJ	AH	FJ	JX	SD	HA	HB	HN	GD	GX	HI	CQ	SC	GZ	YN	XZ	SN	GS	QH	NX	XJ
Rank-eff	28	26	1	7	14	4	16	8	19	5	17	2	24	10	6	3	9	13	20	15	30	21	12	22	11	31	23	18	29	27	25
Rank-inv	27	20	7	5	21	6	1	9	22	11	25	14	18	10	17	2	13	29	4	3	16	24	8	19	12	31	15	23	30	28	26

Fig. 3. Corresponding relationships between the rankings of the input efficiency and input intensity of environmental governance in Chinese provinces

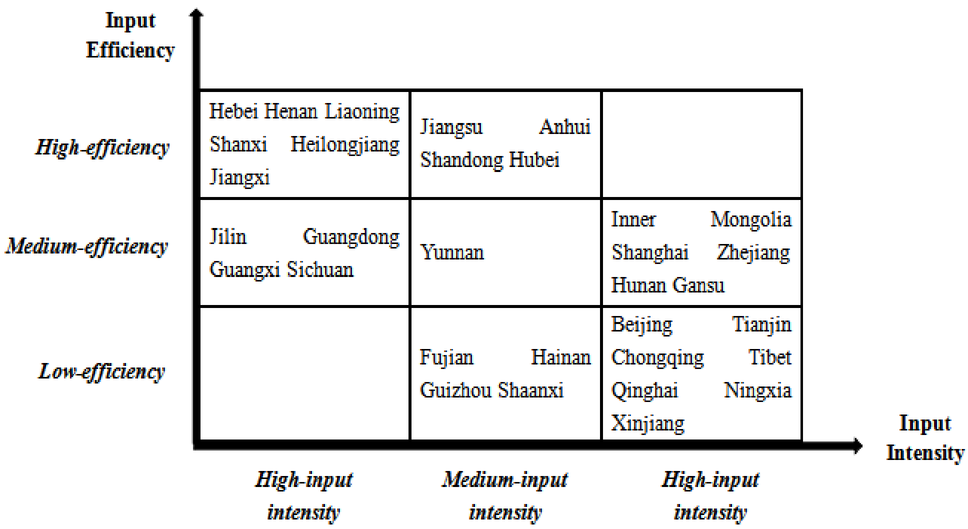


Fig. 4. Nine-grid of the environmental governance input efficiency-input intensity matching in each province

The 31 provinces were categorized as eastern, central, or western to analyze trends in the efficiency of temporal change, spatial distribution features, and the degree to which input intensity and input efficiency rankings matched. the research findings show that: (1) On the whole, China's industrial pollution control input is significantly positively correlated with its output; the population, industrialization level and area of a region have a negative impact on the investment efficiency of environmental governance, whereas GDP, education, urbanization and foreign direct investment positively influence environmental governance. (2) From 1998 to 2014, China's investment efficiency of environmental governance to deal with three industrial wastes showed a general downward trend. The average value of the central provinces is greater than the national average, and the efficiency of environmental governance in each province took on a downward trend. (3) According to the convergence analysis, the efficiency of investment in industrial pollution control in various provinces and regions in China is developing in a differentiated direction. There is a big gap between various regions and provinces when it comes to the efficiency of environmental investment. (4) The investment in industrial pollution control does not match its efficiency in each province, with only six provinces showing the characteristics of "high input and high efficiency". On the basis of the research findings, the following four policy recommendations are proposed:

(1) Strengthen supervision of the input of environmental governance and improve the efficiency of capital utilization

In the 21st century, investment in environmental governance has increased in China. In 1998, China's investment in environmental governance is 72.18 billion yuan. It increased to 101.49 billion yuan in 2000. In 2014, it increased to 957.55 billion yuan. However, the efficiency of environmental governance as measured through SFA has not increased, which is attributable to China's lagging environmental governance structure and regulatory policy. Currently, environmental governance in China is dominated by government investment, whereas investment by enterprises and other investment sources is low; thus, the structure of investment is inappropriate. Additionally, China demonstrates an excessive dependence on command–control terminal governance means and low reliance on market-stimulated frontier governance methods. Additionally, environmental investment lacks a comparative supervision and management mechanism. Numerous forms of equipment and projects required for environmental governance are expensive but have little effect, resulting in the low efficiency of environmental governance. In the future, China should adjust the structure of investment in environmental governance, changing the government-led model, introducing a market incentive mechanism, and strengthening the audit, supervision, assessment, and evaluation of environmental input to improve the efficiency with which funds are utilized while meeting the requirements of environmental governance.

(2) Ensure the coordinated development of environmental governance input and economic and social factors

The results of this study indicate that GDP, education, urbanization, and FDI have a significant positive influence on environmental efficiency, whereas population, industrialization, and field have a significant negative effect on environmental efficiency. Areas with high GDP have high urbanization and high levels of education and technological development. Consequently, environmental governance no longer depends solely on capital input but also depends on improvements in education and technological upgrades. The positive correlation between FDI and the efficiency of environmental input indicates that China's "pollution paradise hypothesis" does not exist. This may be because, although some FDI is accompanied by the transfer of pollution costs, the advanced production technology that this engenders has a "spillover effect". Increases in population and industrial development increase pressure on the environment, hindering improvement of the efficiency of environmental governance. Field is also negatively correlated to the efficiency of environmental governance, which is probably because large provinces are mainly located in western China, and they are relatively undeveloped regions in terms of economy, science, and technology. China should therefore focus on the coordinated development of environmental governance input and economic and social factors and promote the efficiency of governance in the future by increasing the level of economic development, promoting urbanization, raising education levels, introducing FDI, and assimilating advanced foreign technologies.

(3) Adopt differentiated strategies based on the input and output characteristics of environmental governance in various provinces

The distribution of the efficiency of environmental governance in China's 31 provinces from 1998 to 2014 is center > east > west. Most central provinces have a high input–high output state. Economically developed provinces in the east are in either low input–low output or high input–high output states, whereas most western provinces are in a low input–low output state.

Convergence analysis indicated that the efficiency of environmental investment in Chinese provinces is moving toward differentiation and that absolute convergence does not exist. Although relative convergence exists, a large gap also exists between the equilibrium levels of different areas. Therefore, in the future, provinces should improve the efficiency of environmental governance and pay attention to regional coordinated development. They should also optimize the efficiency of environmental governance according to their corresponding development characteristics.

The Chinese government should increase investment in environmental governance in the west and input advanced technologies to cease the continual flow of polluting industries to the west. In some eastern provinces, provincial governments should not pursue only the increase of investment but seek to improve the effect of governance and efficient use of environmental governance funds.

(4) Improve the correlation between input efficiency and input intensity of environmental governance in provinces and optimize the environmental input.

Overall, most provinces exhibit a low correlation between environmental efficiency and investment intensity. Only six provinces have achieved high input–high efficiency statuses. In the future, China should optimize its investment strategy and increase investment in the environmental governance of provinces with medium input intensity–high efficiency and low input intensity–medium efficiency statuses. High input intensity–medium efficiency and medium input intensity–low efficiency province governments should use the flow of environmental funds in a timely manner and improve the efficiency with which environmental governance funds are utilized.

Low input intensity–low efficiency province governments must increase investment appropriately and improve environmental governance depending on their own levels of economic development and environmental pollution. This would improve the efficiency of investment in environmental governance in these areas. Provincial governments should moderately reduce administrative expenses, reduce the number of administrative personnel, and increase the number of technicians. They should also prioritize strengthening substantial technical input and increasing frontline investment in technological innovation rather than terminal sewage equipment to ensure that capital functions effectively.

The research conclusions and policy recommendations are of certain practical value and guiding significance to improving the efficiency of controlling the three industrial wastes in China, but there are still some limitations. The specific performances are as follows: (1) This paper only measured the efficiency of environmental investment without analyzing its influencing factors. In the future, more in-depth empirical research can be conducted to explore the causes of temporal and spatial differences, and work out the optimization path. (2) Limited by data and methods, this paper only studied the environmental governance efficiency of 31 provinces in mainland China from 1998 to 2014.

There is no historical or international comparison. In the future, the scope of time and space can be expanded so that large-scale transnational studies can be carried out in longer time nodes, which can enhance the universality and representativeness of the research conclusions.

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